Measurement of CP violating parameters in the decay $B_s^0 \to J/\psi + \phi$ at DØ

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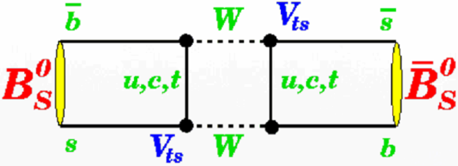
SUSY 2011, September 1, Fermilab

Overview

- Motivation
- Tevatron and DØ
- Event Selection
- Probability Density
- Detector Acceptances, Lifetime Resolution, Flavor Tagging
- Fit Results, S-Wave
- Systematic uncertainties
- Final Results
- Conclusions

Motivation

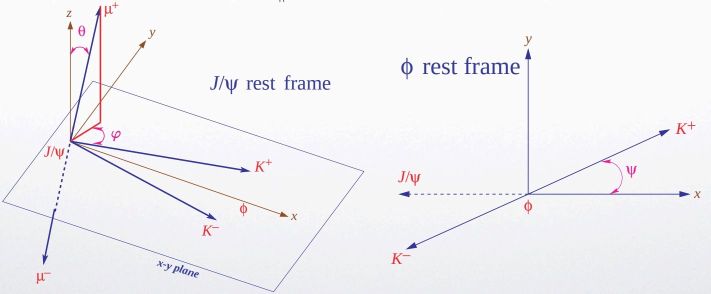
- Two mass eigenstates of the B_s^0 system with sizeable $\Delta M_s = M_H - M_L$ and $\Delta\Gamma_s = \Gamma_L - \Gamma_H$
- Mixing between the flavor eigenstates, interference of decays with and without mixing can cause CP violation
- The CP-violating phase is predicted to be $\Phi_s^{J/\Psi\Phi} = -2\beta_s = -2\arg[-V_{tb}V_{ts}^*/V_{cb}V_{cs}^*] = -0.038 \pm 0.002$,
- New phenomena may alter the phase $\Phi_s^{J/\Psi\Phi} \equiv -2\beta_s + \phi_s^{\Delta}$
- We measure $\Delta\Gamma_s$ and $\Phi_s^{J/\Psi\Phi}$



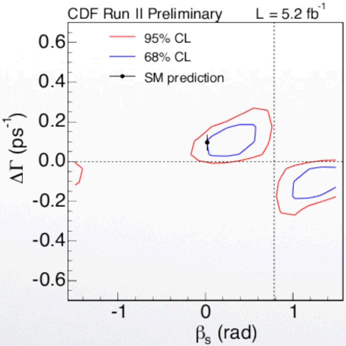
$$\begin{tikzcd} B_s^0 \arrow[rr] \arrow[dr] & & J/\psi\phi \\ & \overline{B_s^0} \arrow[ur] & \end{tikzcd}$$

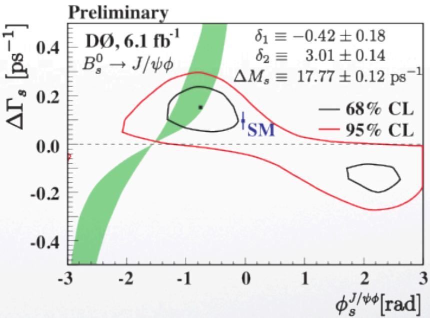
CP eigenstates

- $B_s \to J/\Psi\Phi$ admixture of CP-even/odd states, each of these state has different angular distribution, $P_{\mathbf{B}}(\theta,\varphi,\psi,t) = \frac{9}{16\pi}|\mathbf{A}(\psi,t)\times\hat{n}|$
- $\mathbf{A}(\psi,t) = (\mathcal{A}_0(t)\cos\psi, \frac{-1}{\sqrt{2}}\mathcal{A}_{\parallel}(t)\sin\psi, \frac{i}{\sqrt{2}}\mathcal{A}_{\perp}(t)\sin\psi)$
- For the CP eigenstates:
  - CP-odd (l=1): $A_{\perp}$
  - CP-even (l=0,2): A_0, $A_{\parallel}$

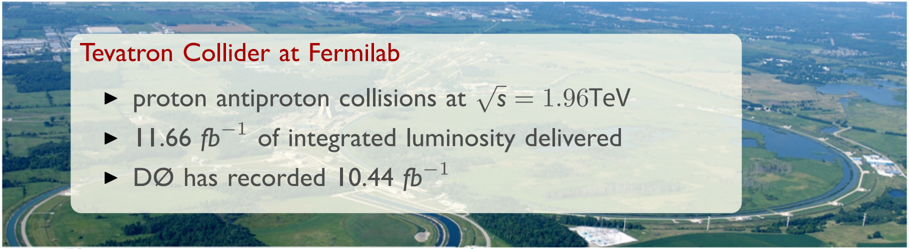


Previous Results CDF and DØ



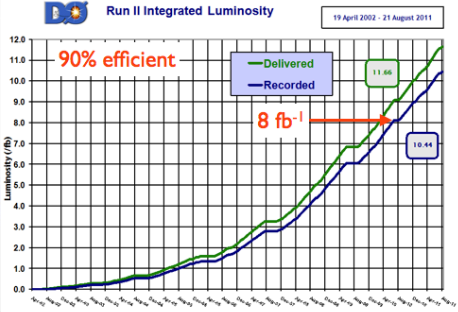


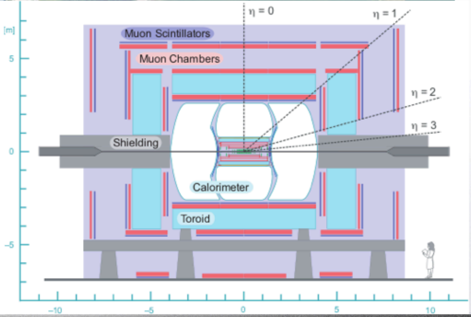
Tevatron and DØ



Tevatron Collider at Fermilab

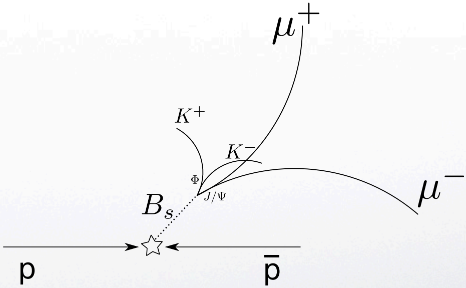
- proton antiproton collisions at $\sqrt{s} = 1.96\text{TeV}$
- 11.66 fb^{-1} of integrated luminosity delivered
- DØ has recorded 10.44 fb^{-1}





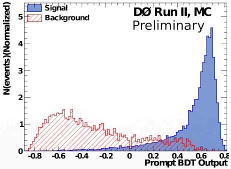
Event Selection

- We require two reconstructed muons of opposite charge.
- Form J/Ψ candidates
- Form Φ candiates from opposite charged tracks assuming the tracks are kaons.
- Form B_s candidates from J/Ψ and Φ candidates.
- Make cuts in the kinematic and the mass windows:
  - $P_t(K^{\pm}) > 0.4GeV$
  - $2.84 < M(\mu^+\mu^-) < 3.35GeV$
  - $0.98 < M(K^+K^-) < 1.04GeV$
  - $5.0 < M(\mu^+\mu^-K^+K^-) < 5.8GeV$

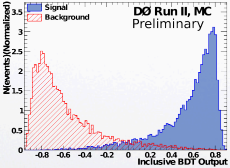


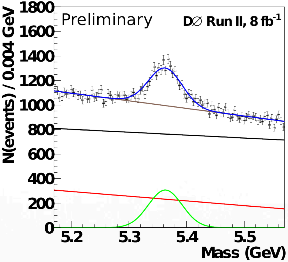
Background suppression

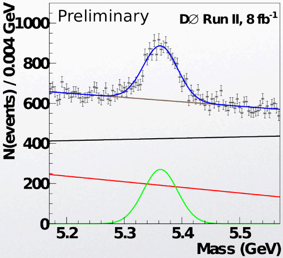
- BDT used to suppress background.
  - Prompt $p\bar{p} \to J/\Psi X$



  - b-inclusive $p\bar{p} \to b\bar{b} \to J/\Psi X$

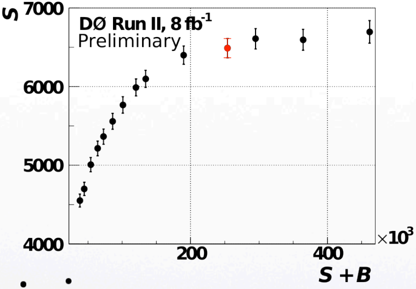


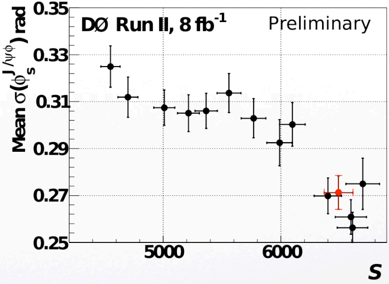




- Simple-Cut as in 2008 PRL, for cross-check and systematic uncertainties.

Optimizing selection





- Tight cuts implies better signal significance but less signal events
- Optimized selection cuts using toy montecarlo studies

Probability Distribution

$$\epsilon(\vec{\omega}) \times \left(\mathcal{B}_s(\lambda; t, \vec{\omega}) \frac{1-D}{2} + \overline{\mathcal{B}}_s(\lambda; t, \vec{\omega}) \frac{1+D}{2} \right) \otimes R(t)$$

where:

- $\vec{\omega} = (\psi, \theta, \varphi) -$ angles
- $D-$ initial flavor tagging dilution
- $\epsilon(\vec{\omega})-$ acceptance, $R(t)-$resolution.

$$\mathcal{B}_s = \left| \left[\sqrt{1-F_s} g(\mu) \mathbf{A} + e^{-i\delta_s} \sqrt{F_s} h(\mu) \mathbf{B} \right] \times \hat{n} \right|^2$$

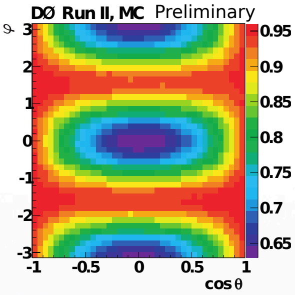
- $\mathbf{A}(\lambda; t, \vec{\omega})-$ P-Wave, $\mathbf{B}(\lambda; t, \vec{\omega})-$ S-Wave.
- $\lambda = (\tau_s, \Delta\Gamma_s, \phi_s^{J/\Psi\phi}, |A_0|^2, |A_\perp|^2, F_s, \delta_s, \delta_\parallel, \delta_\perp, \Delta m_s)$

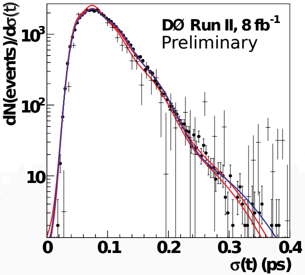
Real Measurables

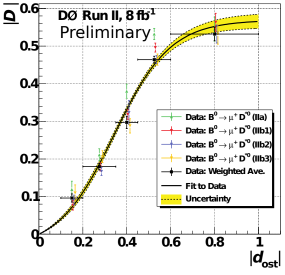
- Two constraints: $\Delta m_s \equiv 17.77 \pm 0.12(\text{ps}^{-1})$, $\cos(\delta_\perp) < 0$

Parameter	Definition
$\lvert A_0 \rvert^2$	$\mathcal{P}$-wave amplitude squared
$\lvert A_\parallel \rvert^2$	$\mathcal{P}$-wave amplitude squared
$\overline{\tau}_s$ (ps)	B_s^0 mean lifetime
$\Delta\Gamma_s$ (ps^{-1})	Heavy-light decay width difference
F_S	K^+K^- $\mathcal{S}$-wave fraction
$\phi_s^{J/\psi\phi}$	CP-violating phase
$\delta_\parallel$	$\arg(A_\parallel / A_0)$
$\delta_\perp$	$\arg(A_\perp / A_0)$
δ_s	$\arg(A_s / A_0)$

Acceptance, Resolution and Flavor Tagging





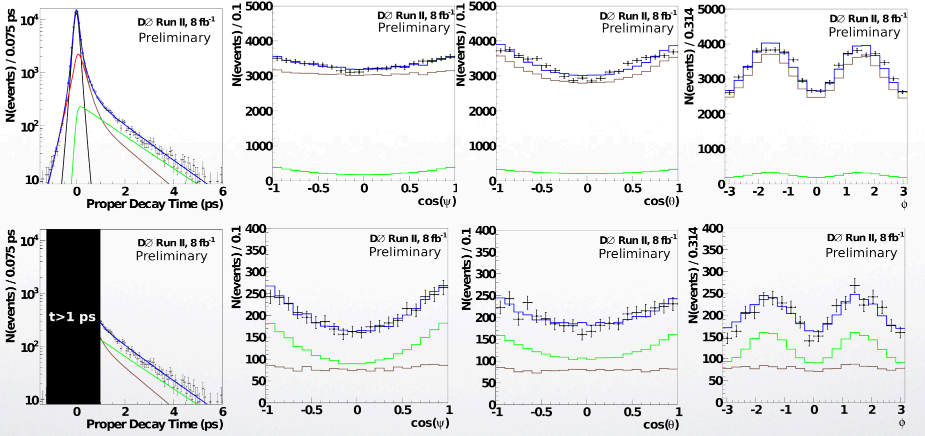


- Data selection criteria were applied to flat MC
- 2D $\cos(\theta), \phi$ acceptance

- Event-by-Event resolution width
- Distribution of proper decay time resolution

- Opposite Flavor tagging using:
  - Muon
  - Electron
  - Jet Charge

Maximum Likelihood Fit

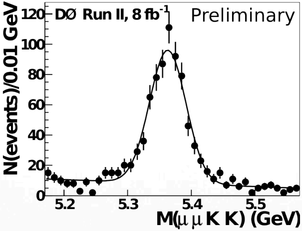


Fit Results

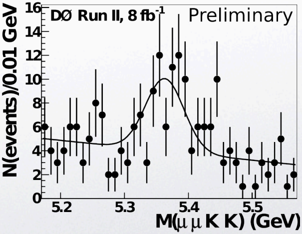
Parameter	BDT Sample	Simple Cut Sample
$\overline{\tau}_s$	$1.426^{+0.035}_{-0.032}$ ps	$1.444^{+0.041}_{-0.033}$ ps
$\Delta\Gamma_s$	$0.129^{+0.076}_{-0.053}$ ps^{-1}	$0.179^{+0.059}_{-0.060}$ ps^{-1}
$\phi_s^{J/\Psi\Phi}$	$-0.49^{+0.48}_{-0.40}$	$-0.56^{+0.36}_{-0.32}$
$\|A_0\|^2$	$0.552^{+0.016}_{-0.017}$	0.565 ± 0.017
$\|A_{\|\|}\|^2$	$0.219^{+0.020}_{-0.021}$	$0.249^{+0.021}_{-0.022}$
$\delta_{\|\|}$	-3.15 ± 0.27	-3.15 ± 0.19
$\cos(\delta_\perp - \delta_s)$	-0.06 ± 0.24	$-0.20^{+0.26}_{-0.027}$
$F_S(eff)$	0.146 ± 0.035	0.176 ± 0.036

Independent determination of F_s

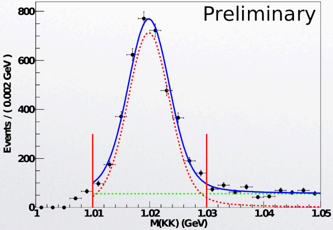
- We independently measure the S-wave fraction by obtaining B_s candidates in the $M(KK)$ distribution from $0.98 - 1.05$ GeV in step of 2 MeV
- The number of fitted B_s signal as a function of $M(KK)$ is fitted with BW with different assumptions assigned as total measurement error
- We measure $F_s = 0.14 \pm 0.01$, consistent with fit estimation



$1.018 < M(K^+K^-) < 1.020$



$1.048 < M(K^+K^-) < 1.050$



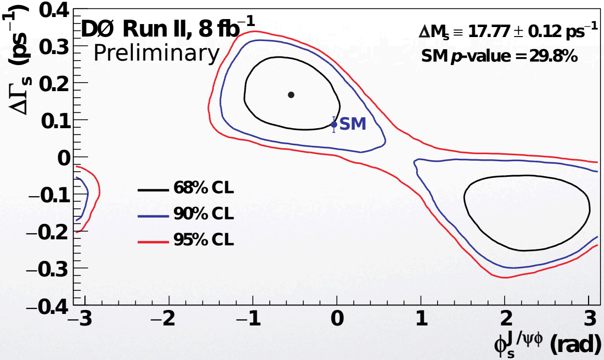
Systematic Uncertainties

- Acceptance systematic from differences between BDT and Simple-cut samples
- Random Variation in resolution parameters
  - Random variations in the resolution parameter values
- Different widths of BW function in $M(KK)$ resolution
  - Different resolution for the Φ mass, important since s-wave is around 15%
- Variation OST calibration curve

Maximum likelihood fit to each alternative fit provide systematic error, which are very small compare to statistical error To combine all the systematical effect of alternative universe, we generate Markov chains of very large states using Markov Chain Monte Carlo (MCMC) method and add them together

$B_s^0 \to J/\Psi\Phi$ Result

P	x
$\overline{\tau}_s$	$1.443^{+0.038}_{-0.035}$ ps
$\Delta\Gamma_s$	$0.163^{+0.065}_{-0.064}$ ps^{-1}
$\phi_s^{J/\Psi\Phi}$	$-0.55^{+0.38}_{-0.36}$
$\lvert A_0 \rvert^2$	$0.558^{+0.017}_{-0.019}$
$\lvert A_{\parallel} \rvert^2$	$0.231^{+0.024}_{-0.030}$
$\delta_{\parallel}$	-3.15 ± 0.22
$(\delta_{\perp}$-$\delta_s)$	$-0.11^{+0.027}_{-0.025}$
$F_S(eff)$	0.173 ± 0.036



Summary

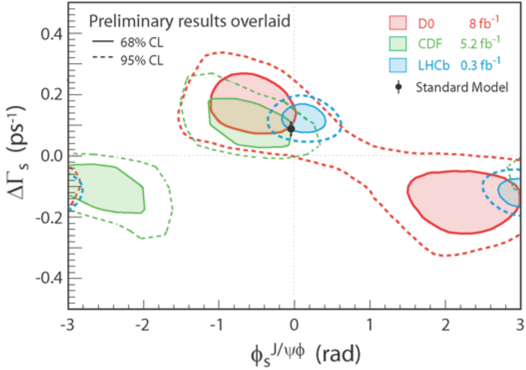
- Measurement of B_s^0 mixing parameters, $(\Delta\Gamma_s, \phi_s^{J/\Psi\Phi})$, polarization amplitudes and phases in the $B_s^0 \to J/\Psi\Phi$ decay using $8fb^{-1}$ data sample.
  - Inclusion of K^+K^- S-wave
- The results are consistent with the SM prediction
- **Combination with other DØ measurements** of CP-Violation parameters will be performed soon

Stay tuned !
Thanks

Backup Slides

LHCb talk (this morning)

$B_s \to J/\psi\phi$



This is NOT an official accurate overlay!! – only an "artist's view"

Bolek Pietrzyk

LHCb results

23

Markov Chain tecnique

- Since ϕ_s is very correlated with $\Delta\Gamma_s$ we want to know how the likelihood depends on these variables.
- Start from some point μ. I use the minimum obtained from the fit.
- Generate a multivariate gaussian ($e^{-\frac{1}{2}(x-\mu)\cdot\Sigma^{1}\cdot(x-\mu)}$.) point x'
- Where Σ is the covariance matrix.
- Calculate $\alpha = L(x')/L(\mu)$
- Generate a random number $r = U(0,1)$
- If $r < \alpha$ accept the new point $\mu = x$
- And continue until reach the amount of points desired.
- We generate 1M events for each Markov Chain